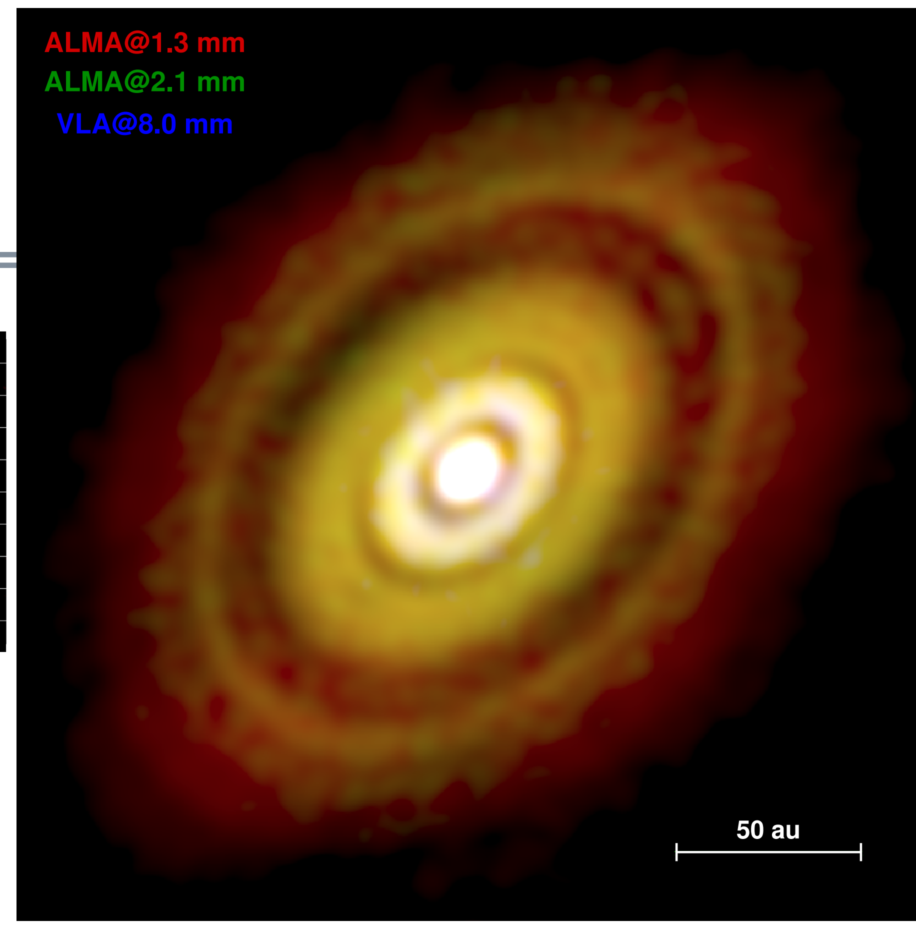
DUST PROPERTIES AND THE ORIGIN OF SUBSTRUCTURES IN THE HL TAU DISK

Carlos Carrasco-González, IRyA-UNAM

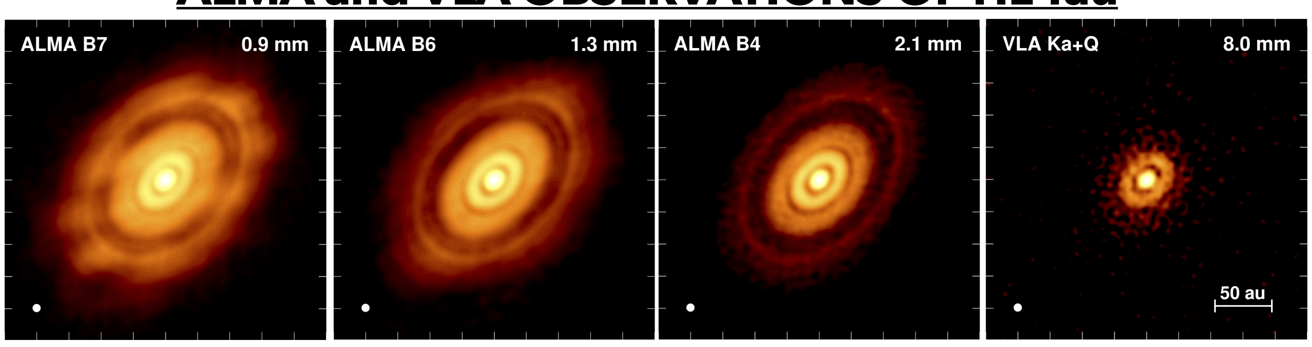
Anibal Sierra, Mario Flock, Zhaohuan Zhu, Thomas Henning, Enrique Macías, Claire Chandler, Roberto Galván-Madrid, Guillem Anglada, Hendrik Linz, Mayra Osorio, Luis F. Rodríguez, Leonardo Testi, José M. Torrelles, Laura Pérez, and Yao Liu

RINGS EVERYWHERE...

The detection of multiple bright and dark rings in ALMA images of the HL Tau disk in 2014 revolutionized our vision on disk evolution and planet formation. Five years later, these substructures have revealed as intriguingly common in protoplanetary disks of all masses and ages. Their origin is still under debate. There is a natural tendency to interpret the presence of multiple rings as a sign of (proto)planets present in the disk. But, they can actually be formed by a number of other mechanisms not involving already formed (proto)planets. In any case, there is a general consensus that substructures have an important role for dust growth in the disk and the formation of planetary systems. If bright rings are most probably concentrating large amounts of big particles, what would make them excellent places to grow new planets. However, the high density of these rings makes millimeter emission optically thick, and obtaining dust properties is not an easy task, even with ALMA. Then, in the last years it has become clear that complementary high quality images at longer, optically thinner wavelengths are also necessary to understand the origin of substructures and its role in the birth of planetary systems.



ALMA and VLA OBSERVATIONS OF HL Tau



Highest quality set of millimeter images in a protoplanetary disk.
Wide range of wavelengths —> very different optical depths.
Resolution of 50 mas —> 7.5 au

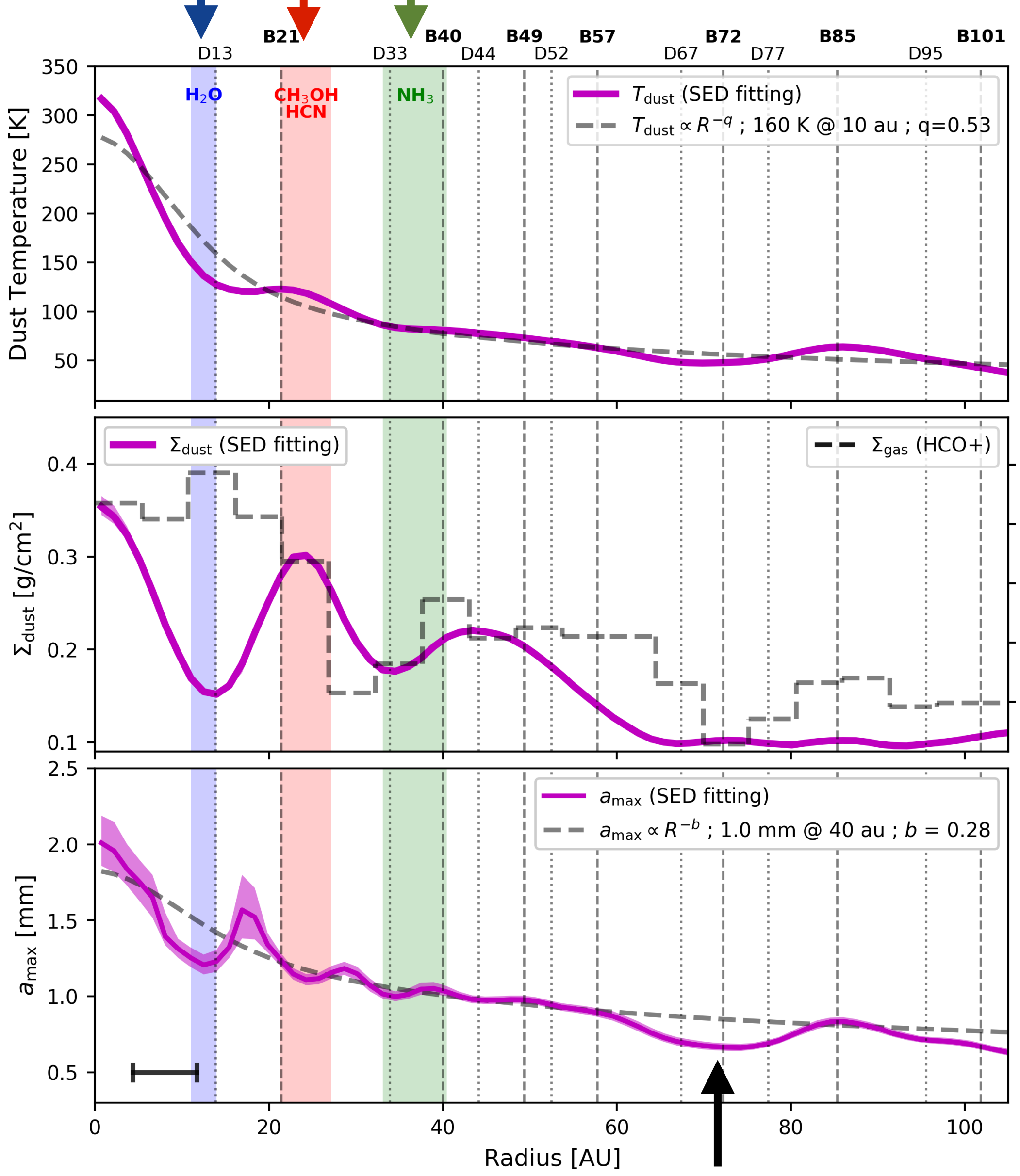
At each radius, we model the SED to a simple disk model including scattering and absorption in the dust opacity.

RADIAL DUST PROPERTIES AND THE ORIGIN OF RINGS

ICE LINES

METHANOL

WATER **AMMONIA**



DUST AND GAS GAP OPEN BY MASSIVE PLANET

The analysis of the ALMA and VLA images allows to “measure“ the dust properties, temperature, density and particle sizes, at each radius. The high angular resolution (~7.5 au) allows to resolve substructures and to distinguish different characteristic between dark and bright rings.

Dust have already grown up to sizes of a few millimeters in almost the whole disk.

Bright rings contain higher density dust and larger particles than the adjacent dark rings.

The origin of substructures seems to be different for the internal (<50 au) and the external (>50 au) disk.

The wide dark ring at 60-80 au, contains the smallest particles (<1 mm). This dust gap also coincides with a gas gap. All this is consistent with this gap being formed by the presence of a (proto)planet at its center. Most likely, a massive planet, orbiting at 70 au and formed in an earlier stage of the disk evolution.

Rocky planets will form through dust growth in the internal part of the disk. We found that internal bright and dark rings show lower contrast in their dust properties, and they seem to be well associated with the ice lines of some of the most important molecules in the disk: Water, Methanol, and Ammonia. This strongly suggests that the sublimation or condensation of these molecules have a strong impact on dust growth in the disk.

Now, click here

Carrasco-González et al. 2019, ApJ, 883, 21